High Energy Lithium Batteries for Electric Vehicles

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Zenlabs Energy Inc.

2018 DOE Vehicle Technologies Office
Annual Merit Review
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Project ID: BAT247

Program Overview

TIMELINE

- Project start date: Jun 2014
- Project end date: Dec 2018
- Percent complete: ~89%

BARRIERS

- Meet USABC EV energy and power cell specs
- Meet cycle life and calendar life
- Enable a cell cost target of 100$/kWh

BUDGET

- Total project funding:
  - ✓ DOE share: $3,859,246
  - ✓ Zenlabs & partners share: $3,859,246
- Funding received in FY2017: $734,383
- Funding for FY2018: $0
  (currently under no cost extension)

PARTNERS

DAIKIN

A123 SYSTEMS

Nanoscale Components

AsahiKASEI

3M

DUPONT

Relevance & Objectives

- **Goals:**

  Develop high capacity cathode and anode materials, screen commercial electrolytes and separators, optimize pre-lithiation process, and integrate to build high capacity pouch cells that meet the USABC electric vehicle (EV) battery goals for CY 2020

- **Objectives and Tasks:**

✓ Develop high capacity cathode and anode materials and electrodes
✓ Mitigate cycle life challenges associated with Silicon anodes and Ni-rich cathodes
✓ Develop an economical and manufacturable pre-lithiation process
✓ Develop a large-capacity (>50Ah) large footprint cell
✓ Establish an optimized cell design to ensure meeting the cell metrics, safety and cost targets

- **Deliverables:**

  Demonstrate & deliver cells that meet the USABC EV cell targets with independent validation from the National Labs (INL, SNL, & NREL)

- **USABC EV Cell Targets for 2020:**

End of Life Characteristics at 30°C	Units	Cell Level
Peak Discharge Power Density, 30 s Pulse	W/L	1500
Peak Specific Discharge Power , 30 s Pulse	W/kg	700
Peak Specific Regen Power , 10 s Pulse	W/kg	300
Useable Energy Density @ C/3 Discharge Rate	Wh/L	750
Useable Specific Energy @ C/3 Discharge Rate	Wh/kg	350
Useable Energy @ C/3 Discharge Rate	kWh	N/A
Calendar Life	Years	15
DST Cycle Life	Cycles	1000
Selling Price @ 100K units	$/kWh	100
Operating Environment	°C	-30 to +52
Normal Recharge Time	Hours	< 7 Hours, J1772
High Rate Charge	Minutes	80% ΔSOC in 15 min
Maximum Operating Voltage	V	N/A
Minimum Operating Voltage	V	N/A
Peak Current, 30 s	A	400
Unassisted Operating at Low Temperature	%	> 70% Useable Energy @ C/3 Discharge rate at -20 °C
Survival Temperature Range, 24 Hr	°C	-40 to+ 66
Maximum Self-discharge	%/month	< 1

Milestones and Gates

Current Status

2018 → Program end date: Dec 31, 2018

Task Number	Major Project Tasks	PROJECT TIME																
		YEAR 1				YEAR 2				YEAR 3				YEAR 4 + NCE				
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17
8	**SUMMARY OF MAJOR PROJECT DELIVERABLE**																	
6.1.5	Ship 12 (twelve) 20 Ah baseline cells fabricated by Zenlabs to selected National Labs for independent testing		◆															
6.2.14	Build and test 1 Ah cells from cell build #1 as an internal build and report and use learning for future cell builds					◆												
6.3.14	Ship 28 (twenty-eight) 11 Ah capacity cells fabricated by Zenlabs from cell build #2 to the National Labs for independent testing											◆						
6.4.9	Build and test 11 Ah cells from cell build #3 as an internal build and report and use learning for final cell build															◆		
6.5.14	Ship 11 Ah and 40+ Ah capacity cells fabricated by Zenlabs from cell build #4 to the National Labs for independent testing																	◆
7.1.3	Deliver final USABC project cell cost model & report																	◆
9	**REVIEW AND DECISION GATES**																	
9.1	Down-select best cathode composition (Li, Ni, Co, Mn & amount of Li_2MnO_3), conducting coating (polymer, carbon or metallic) and dopant to be integrated in 1Ah cells from cell build #1				◆													
9.2	Down-select best prelithiation process conditions (lithiation loading, time, speed, drying, handling, etc.) to build 1Ah cells from cell build #1				◆													
9.3	Down-select and focus material development efforts on the most promising Si-based anode approach (Si-alloys and nSi-C and SiOx-C composites)					◆												
9.4	Freeze best separator material to be used in remaining cell builds											◆						
9.5	Down-select best prelithiation process to build 11 Ah and 40+ Ah cells from cell build #4											◆						
9.6	Freeze best cathode blend to build 11 Ah cells from cell build #3															◆		
9.7	Freeze best Si-based anode composite to build 11 Ah cells from cell build #3															◆		
9.8	Freeze best electrolyte formulation to be used in remaining cell builds															◆		

← Baseline (complete)

← Build #1 (complete)

← Build #2 (Complete)

← Build #3 (ongoing)

← complete

← complete

← complete

← complete

← complete

ongoing

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Approach & Partnerships

Approach:

Material & component development

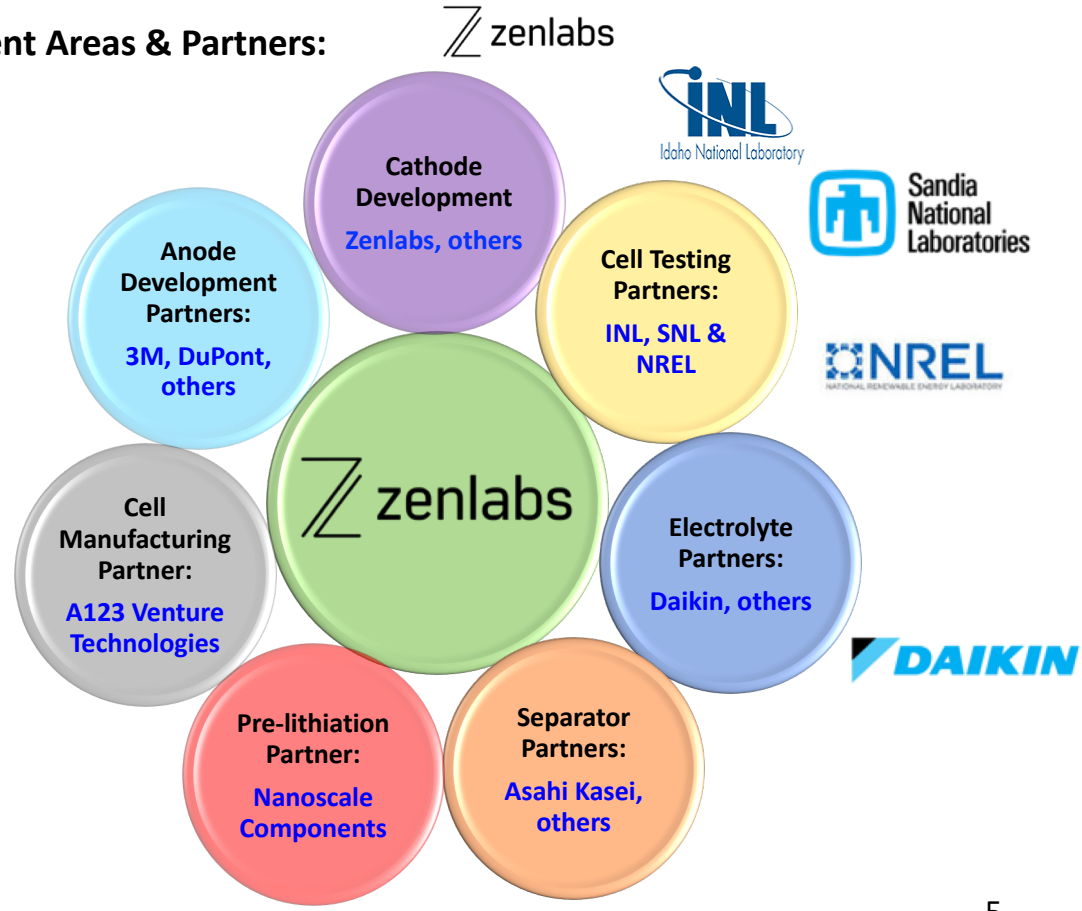
- Anode screening/development
- Cathode screening/development
- Pre-Lithiation development
- Electrolyte screening
- Separator screening

Cell development

- Cell modeling
- Cell building
- Cell testing

Develop and deliver high capacity cells meeting USABC EV specifications

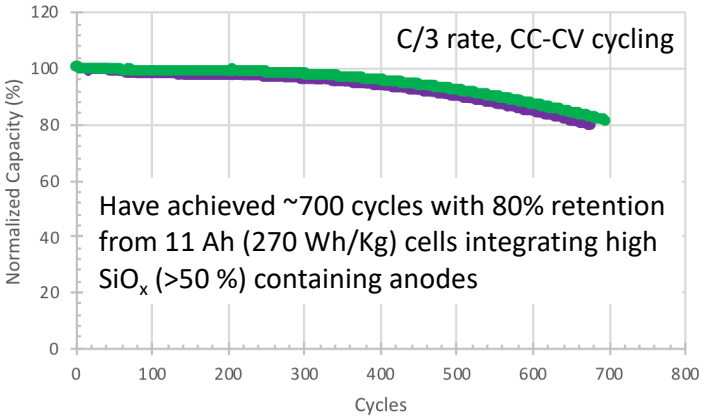
Development Areas & Partners:



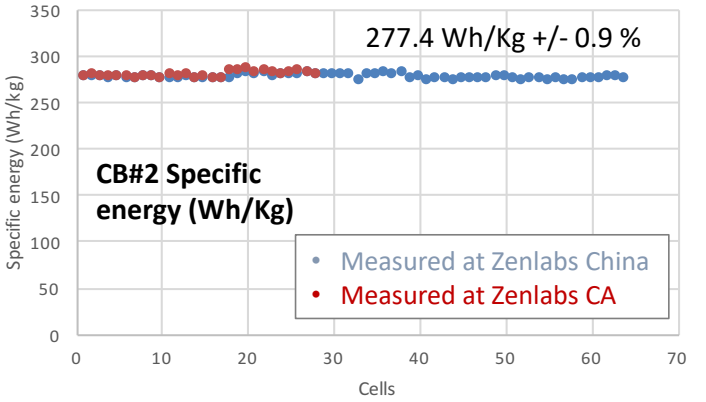
Technical Accomplishments (Cell Development)

Cell Build Schedule

Cell Builds	*Purpose*	*Status*
Baseline	Beginning of the program cell baseline	Complete
Cell build #1	Align with cell manufacturer	Complete
Cell build #2	Deliver cells to the National Labs	Complete
Cell build #3	Internal development to freeze final cell design	Ongoing
Cell build #4	Final cell deliverable to National Labs	Ongoing



- Have achieved ~700 cycles with 80% retention from 11 Ah (270 Wh/Kg) cells integrating high SiO_x (>50 %) containing anodes and Ni-rich/HCMR™ cathode blends
- 28 cells from cell build #2 (11 Ah, 280 Wh/Kg) were delivered to the National Labs
- Good cell reproducibility was observed across ~60 assembled pouch cells



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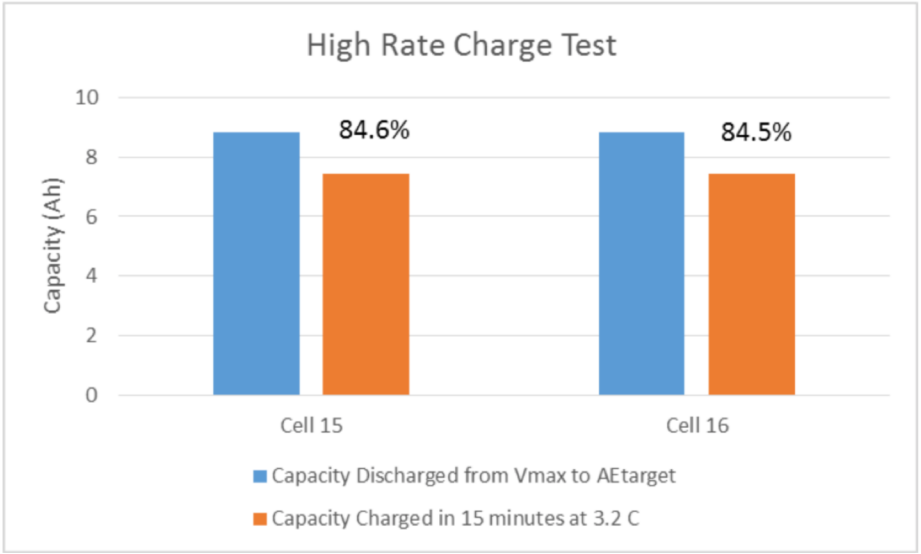
Fast Charge Test

- **High Rate Charge**
  - Both exceed 80% Goal
  - Current began to taper at 8.3 minutes, tapered to 12.8 A at end of 15-minute charge
  - 5 °C skin temperature rise at end of charge

Cell build #2 cells pass the High Rate test charging > 80% capacity in 15 min at a 3.2C rate



Envia Build #2 EV Cells	
Vmin (zero/pulse)	2.3/2.2 V
Vmax (op./pulse)	4.35/4.45 V
Vnominal	3.45 V
Rated Capacity (C/3)	11 Ah
Weight (kg)	0.14221
Volume (L)	0.06047
Chemistry	NMC/SiOx-C

Capacity	
Discharge	8.81 ± 0.013 Ah
Charge (3.2C)	7.44 ± 0.002 Ah
% Capacity Restored	84.5 ± 0.001 %

Data measured at Idaho National Laboratory (INL)

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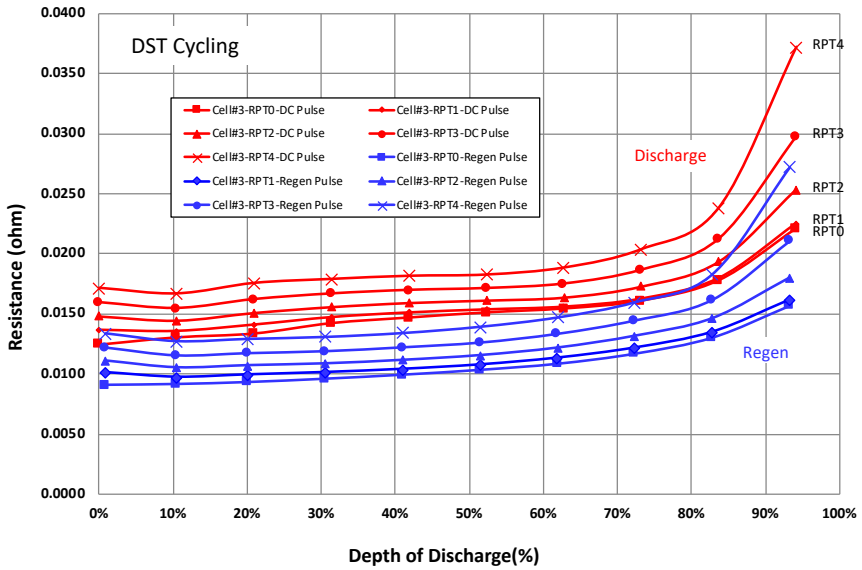
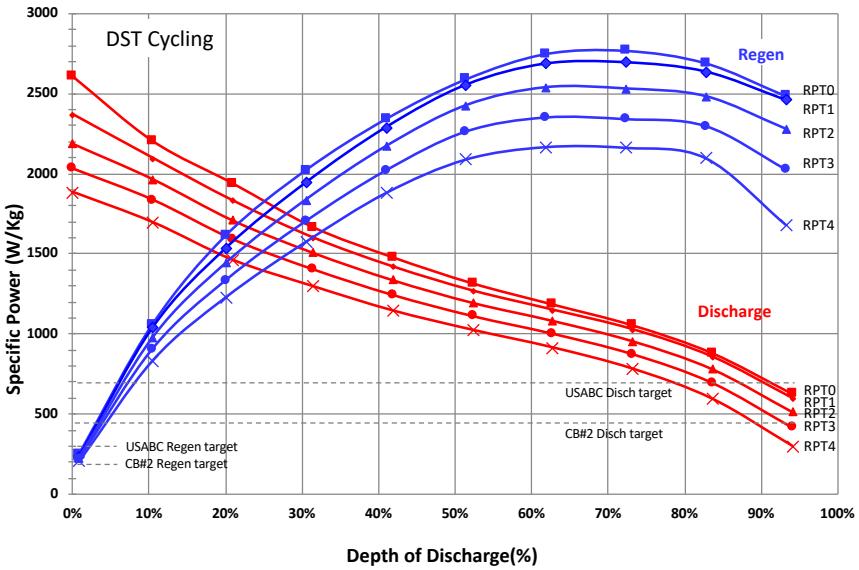
DST Cycling Performance of CB#2

Resistance



Power



Based on CB#2 EOL targets, Build #2 cells continued to meet the power and energy requirements after RPT 4 (~400 DST cycles at 30 deg C)

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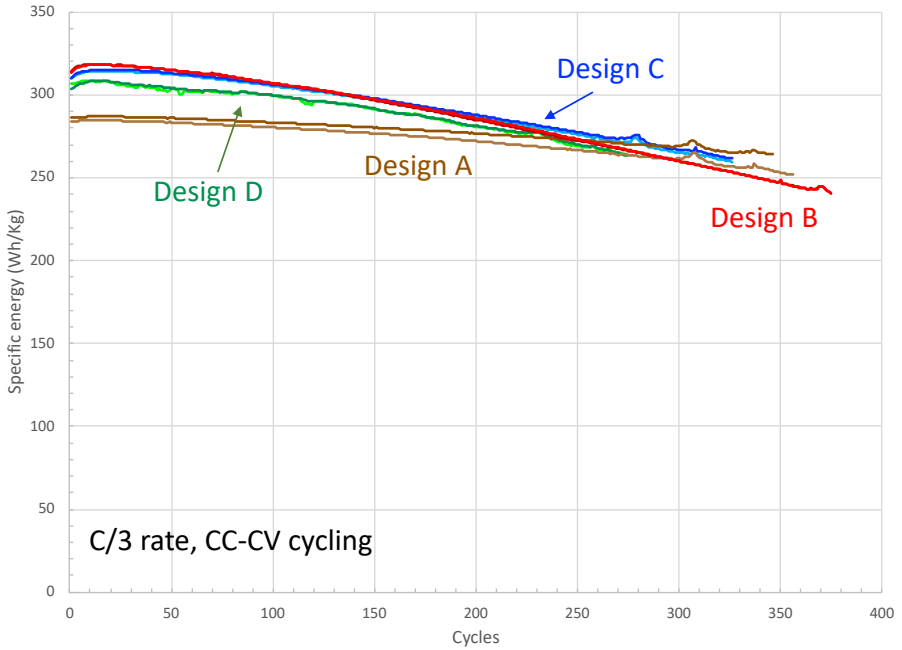
Cell Development Targeting > 300 Wh/Kg

- Cell Build #3 (CB#3) development is ongoing to freeze the final cell deliverable design targeting a specific energy >300 Wh/Kg and 1000 cycles
- Cell development is taking place at Zenlabs recently upgraded cell prototyping facility that includes a new dryroom, coater, stacking machine, and dehumidifying equipment in the coating area
- The program encountered delays due to problems with the incoming materials and high humidity
- Additional designs are being tested with improved materials and equipment to freeze the final design



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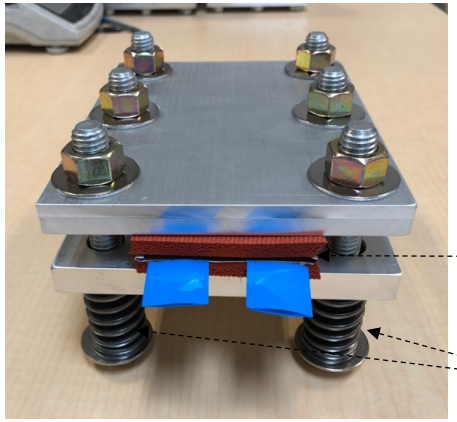
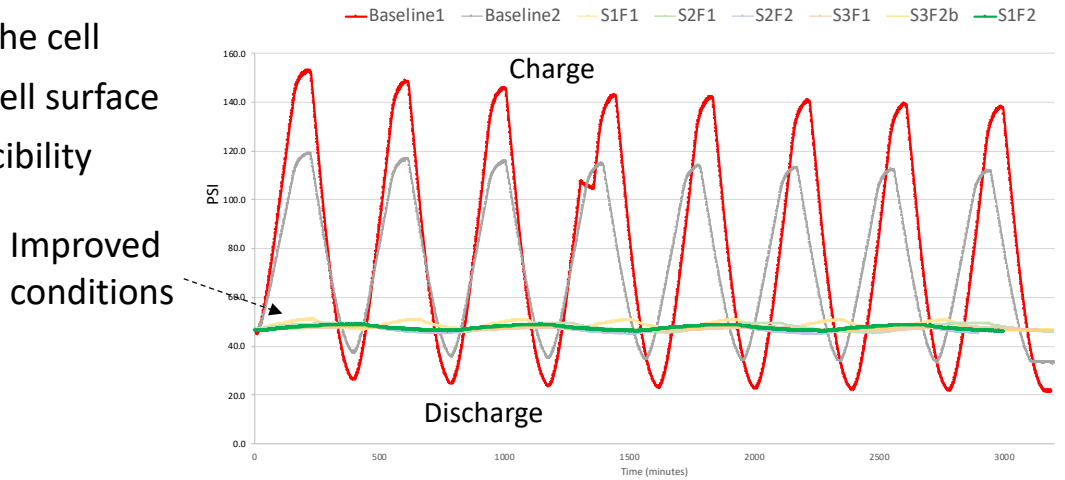
Cell Clamping Optimization

Optimizing the cell clamping conditions using different springs and foams to:

- Minimizing pressure oscillations experienced by the cell
- Improving pressure uniformity across the entire cell surface
- Improving cell-to-cell clamping pressure reproducibility



Note:
1. two baselines use different rigid clamping hardware
2. Pressure was normalized to ~44 PSI to compare amplitude of oscillations



- Different springs & foams were evaluated during charging and discharging of the cell
- Have down-selected the best Spring & Foam combination for cycling validation

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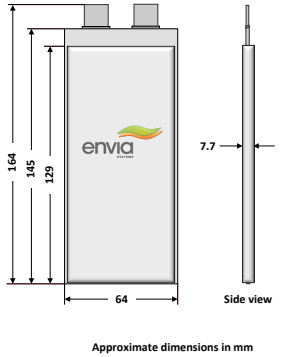
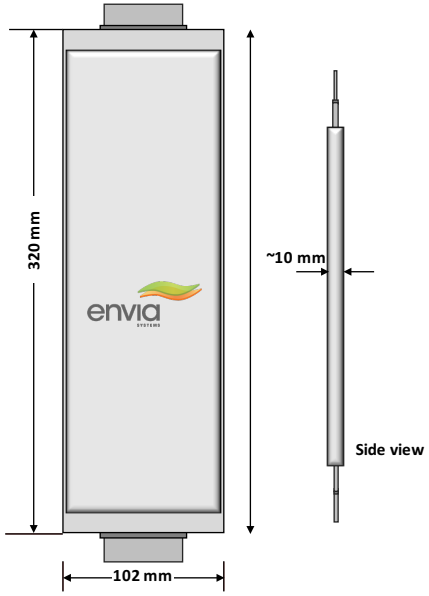
50 Ah Capacity Cell Development

- Zenlabs has developed an 11 Ah capacity footprint cell (145 mm x 64 mm) used during the majority of the cell development (cell build #1, #2, #3 & #4)
- Zenlabs is developing a larger 50 Ah capacity footprint cell (320 mm length x 102 mm width) to used in the final cell deliverable (cell build #4)
- The final USABC program cell deliverable will Include delivering both 11 Ah & 50 Ah capacity cells to the National Laboratories for independent testing



11 Ah cell footprint
(145 mm x 64 mm)



50Ah cell footprint
(320 mm x 102 mm)

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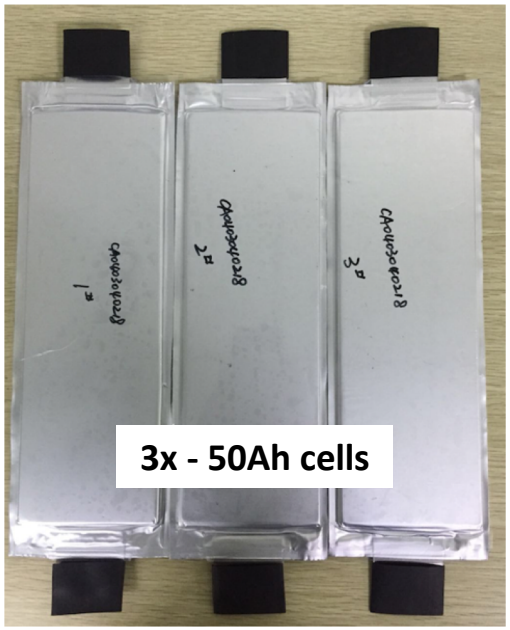
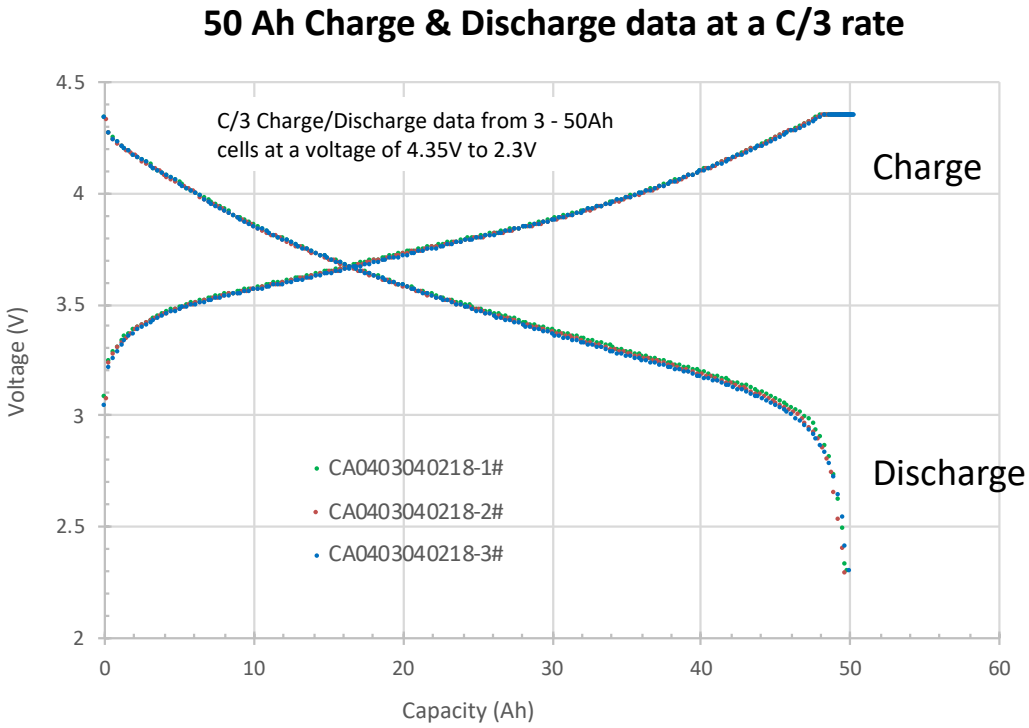
50 Ah Capacity - Large Footprint Cells

Large footprint cells were successfully built and show consistent electrochemical behavior





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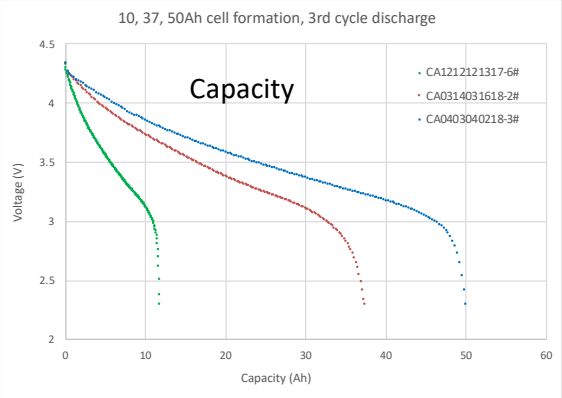
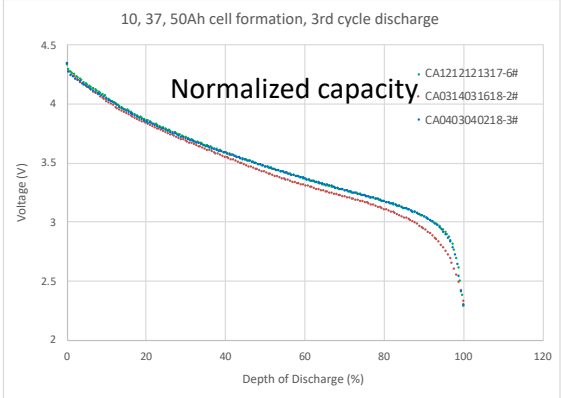
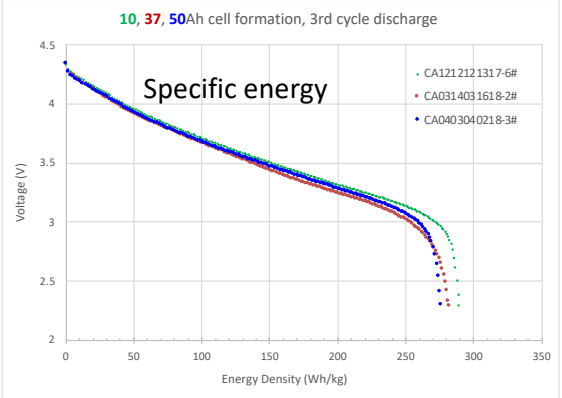
50 Ah Capacity Large Footprint Cell Data







			Cell data						Design model			
Build	**Cell footprint (mm)**	**Cell #**	**OCV (V)**	**Resistance (mOhms)**	**Weight (g)**	**Thickness (mm)**	**Capacity (Ah)**	**Specific energy (Wh/Kg)**	**Weight (g)**	**Thickness (mm)**	**Capacity (Ah)**	**Specific energy (Wh/Kg)**
Baseline 11 Ah	145 x 64	Avg.	3.05	2.6	137.5	7.50	11.30	286.0	138.5	7.2	11.2	284.0
37Ah cells	320 x 102	1	2.89	2.4	465.3	7.81	37.14	275.3	457.1	7.3	36.7	281.8
		2	2.93	2.9	456.6	7.66	37.28	281.7				
50 Ah cells		1	3.14	1.5	634.0	10.16	49.77	275.7	630.8	10.0	51.3	285.9
		2	3.11	1.3	633.2	10.51	49.63	274.9				
		3	3.05	1.2	632.2	10.51	49.94	276.2				

- Large footprint cells were successfully built meeting the expected capacity and energy targets
- Cycle life is currently being evaluated

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Responses to Reviewers Comments

Comment: “As impressive as these performance numbers are, the reviewer observed the results are not much more impressive than the recent high-energy commercial 18650 cells that provide 265 Wh/kg and 800 Wh/l with graphitic anodes at the cell level.”

Response: The program has been structured to continuously increase the energy of the cell as It progresses. Current development and final cell deliverable are targeting a specific energy > 300 Wh/Kg and 1000 cycles. It is true that state-of-art graphitic 18650 cells are able to show high energy, but it is unlikely they will be able reach >300 Wh/Kg. Using high capacity Silicon based anodes enable reaching greater energies and at the same time allow enough flexibility in the design to address power, fast charge, safety and cost.

Comment: “The reviewer noted this project is certainly challenging with many problems to overcome.”

Response: We agree with the reviewer’s comment that it is a challenging problem to develop cells meeting the final target specification of performance, cost and safety. For this reason we continue to explore and evaluate the most promising materials, components and processes by partnering with leading suppliers and integrating and evaluating their performance in large capacity pouch cells.

Remaining Challenges and Barriers

- Ensure receiving reliable cell components and materials with the desired specifications and performance for the remaining cell development
- Incorporate the best learning from the materials and cell designs and assemble Cell build #3 designs in 11 Ah capacity pouch cells targeting a specific energy >300 Wh/Kg and 1000 cycles.
- Obtain sufficient cell data to properly down-select the final design of the program
- Complete the development of the large footprint cells to produce reliable and high quality cells

Proposed Future Research

- Complete building and testing of cell build #3 designs targeting >300 Wh/Kg and 1000 cycles
- Complete cycle life evaluation for different clamping conditions to down-select optimal clamping conditions to be used for the final cell deliverable
- Based on cell test results, down-select the Final cell design of the program
- Complete cell optimization of the large footprint cell design (320 mm x 102 mm)
- Complete Cell Build #4 and deliver cells to the National Labs for independent testing

Summary

- Completed assembly and delivery of build #2 cells to the National Labs for independent testing. Cells showed good reproducibility in physical and electrochemical performance
- Build #2 cells are 11 Ah capacity with specific energy of 280 Wh/Kg and continued to meet the CB#2 EOL power and energy targets after RPT 4 (~400 DST cycles at 30 deg C). Cells also pass the fast charge test showing ~84% capacity recovery after 15 minute charge
- Have down-selected the best foam and spring combination to minimizing pressure oscillations, improving pressure uniformity and cell-to-cell pressure reproducibility
- Successfully designed and built initial 50 Ah capacity large footprint cells (320 x 102 mm) showing consistent electrochemical behavior and meeting the initial design capacity and energy targets